

# ECE 440 - Introduction to Computer Networks

Spring 2020

# Chapter 4: outline

## 4.1 Overview of Network layer

- data plane
- control plane

## 4.2 What's inside a router

## 4.3 IP: Internet Protocol

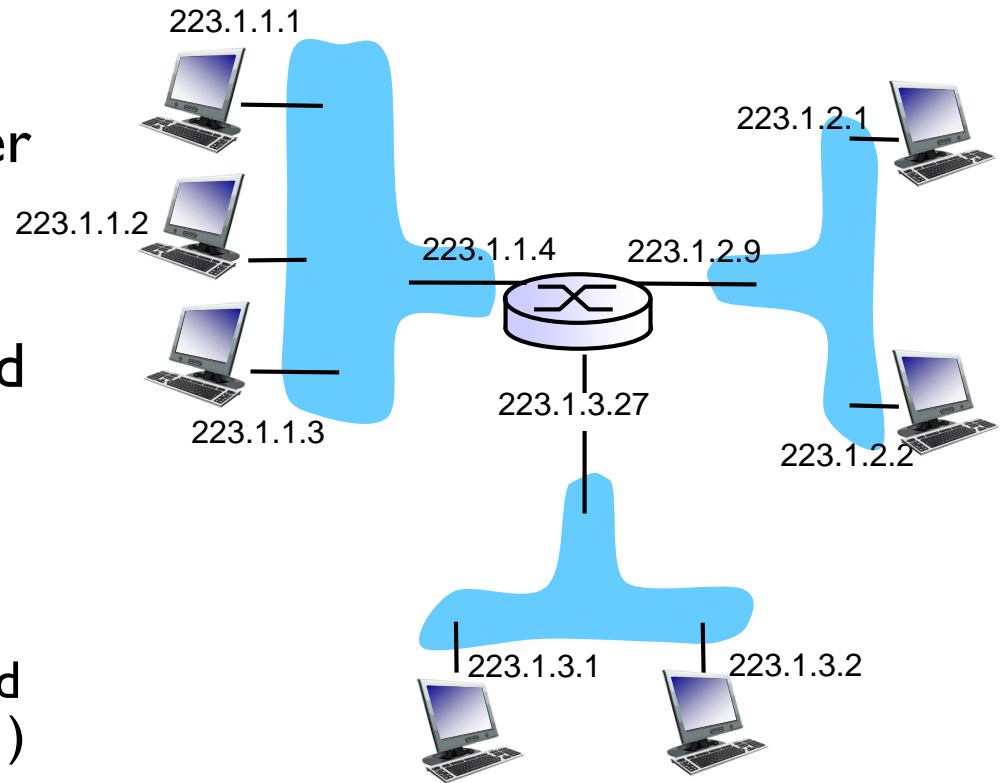
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

## 4.4 Generalized Forward and SDN

- match
- action
- OpenFlow examples of match-plus-action in action

# IP addressing: introduction

- **IP address:** 32-bit identifier for host, router interface
- **interface:** connection between host/router and physical link
  - router's typically have multiple interfaces
  - host typically has one or two interfaces (e.g., wired Ethernet, wireless 802.11)
- **IP addresses associated with each interface**



$$223.1.1.1 = \underbrace{11011111}_{223} \underbrace{00000001}_1 \underbrace{00000001}_1 \underbrace{00000001}_1$$

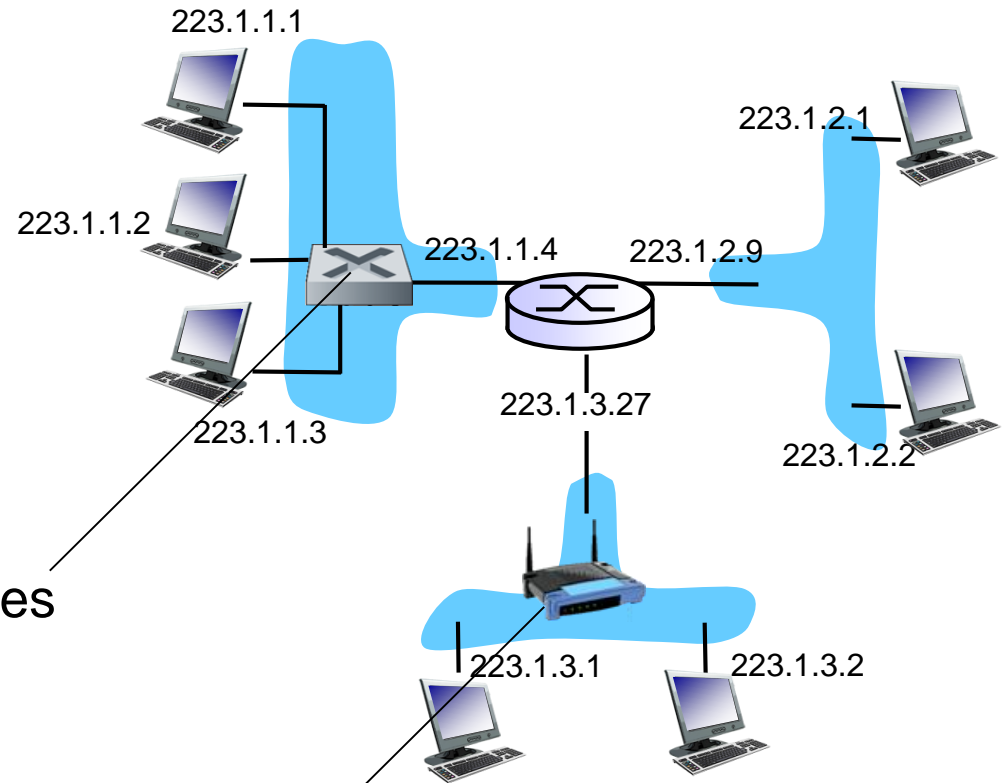
# IP addressing: introduction

*Q: how are interfaces actually connected?*

*A: we'll learn about that in chapter 5, 6.*

*A:* wired Ethernet interfaces connected by Ethernet switches

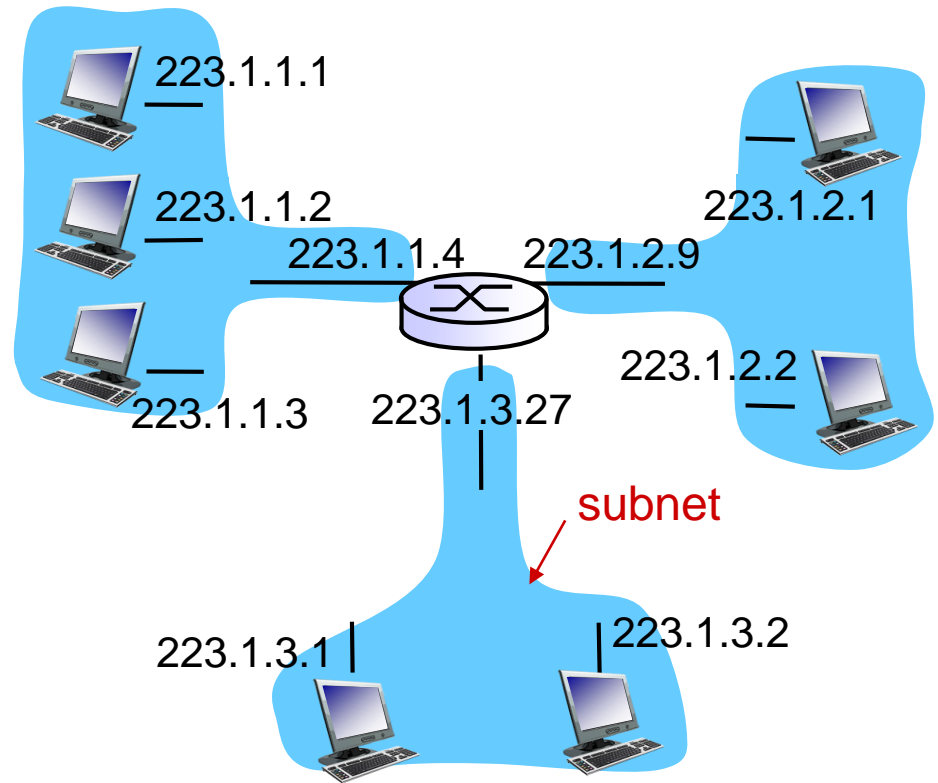
*For now:* don't need to worry about how one interface is connected to another (with no intervening router)



*A:* wireless WiFi interfaces connected by WiFi base station

# Subnets

- IP address:
  - subnet part - high order bits
  - host part - low order bits
- *what 's a subnet ?*
  - device interfaces with same subnet part of IP address
  - can physically reach each other *without intervening router*

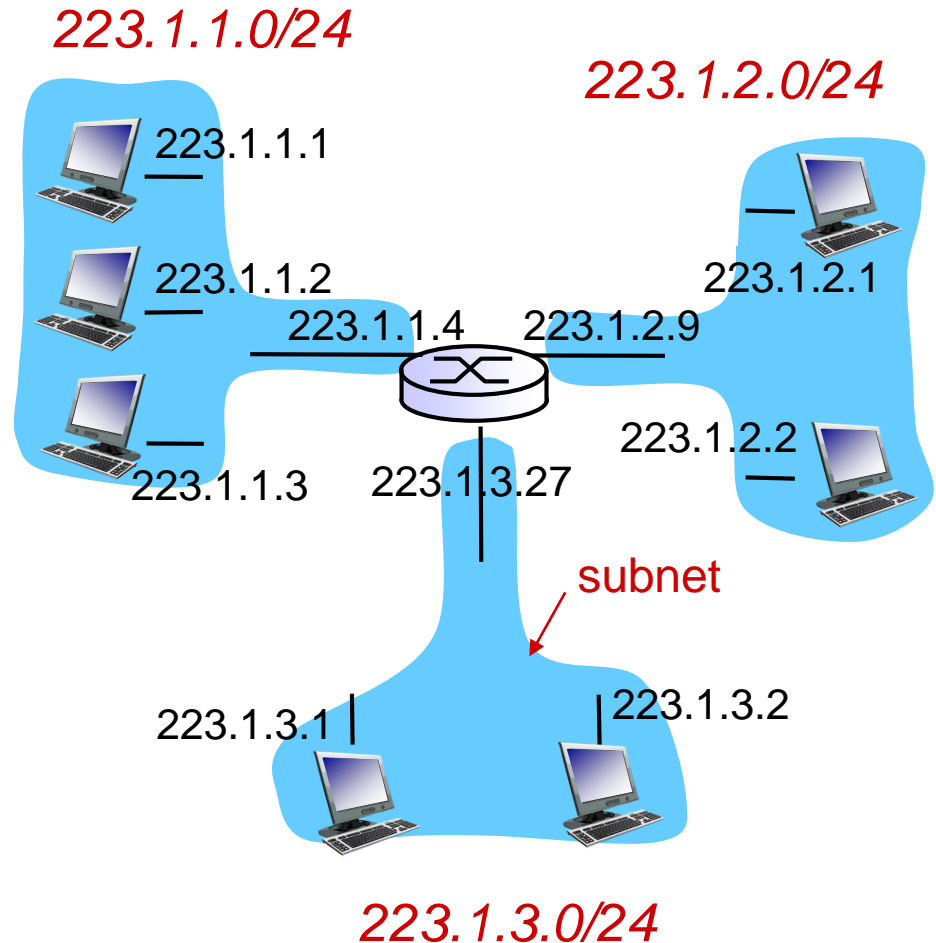


network consisting of 3 subnets

# Subnets

## *recipe*

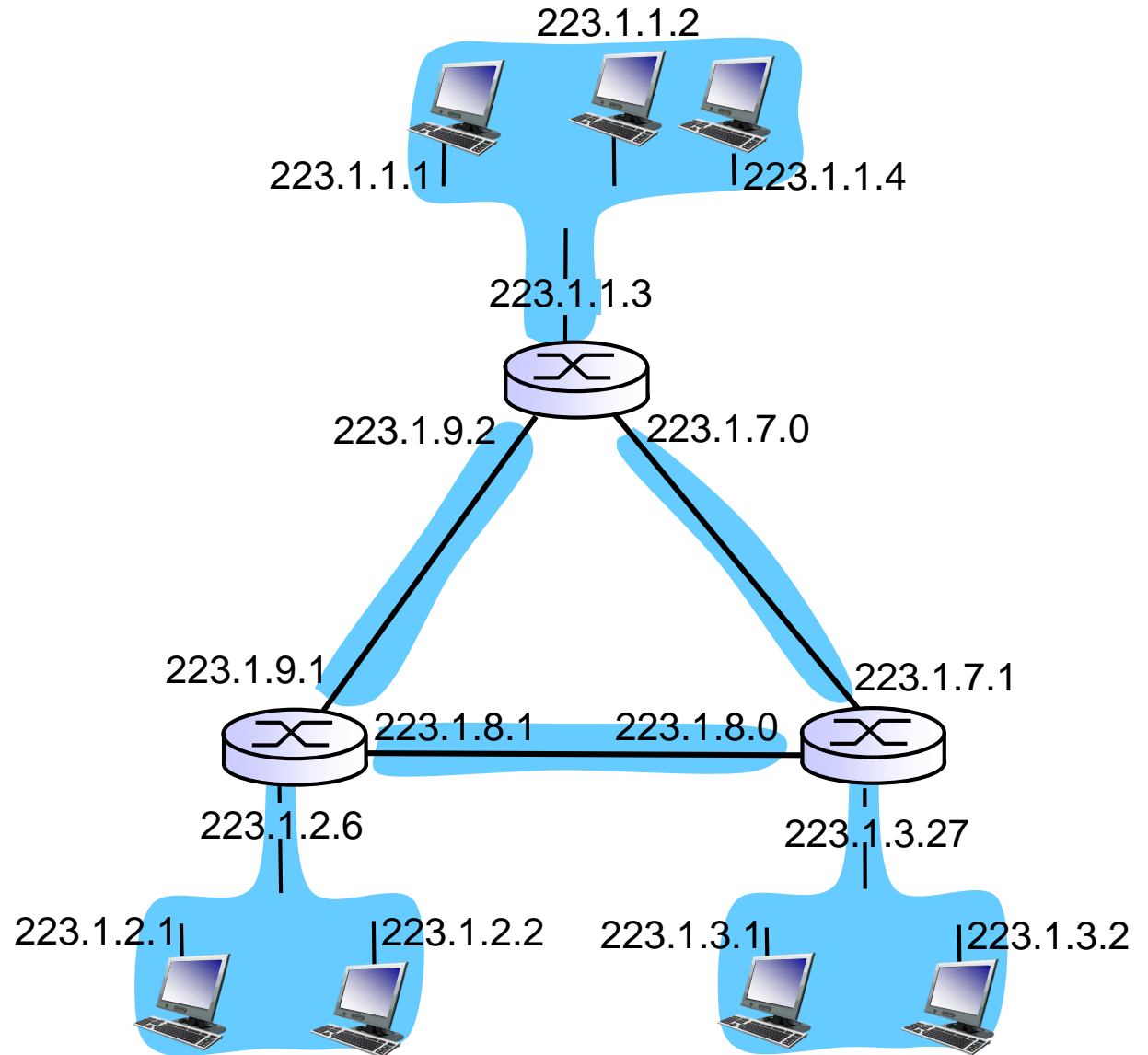
- to determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24

# Subnets

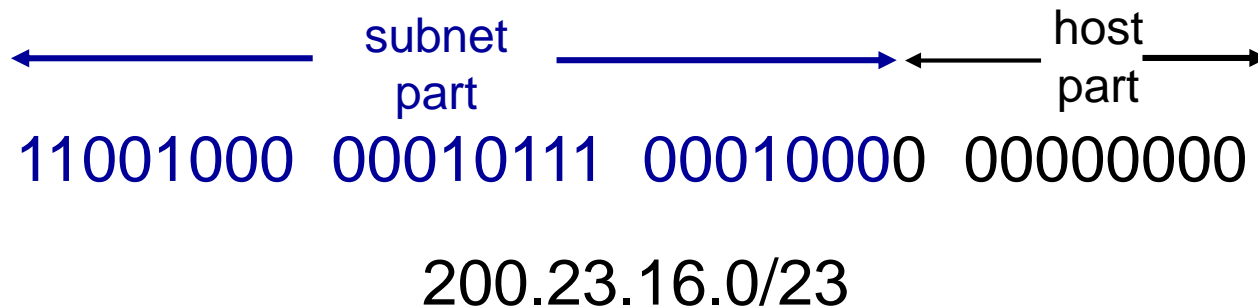
how many?



# IP addressing: CIDR

## CIDR: Classless InterDomain Routing

- subnet portion of address of arbitrary length
- address format: **a.b.c.d/x**, where x is # bits in subnet portion of address





# IP addresses: how to get one?

**Q:** How does a *host* get IP address?

- hard-coded by system admin in a file
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- **DHCP: D**ynamic **H**ost **C**onfiguration **P**rotocol: dynamically get address from as server
  - “plug-and-play”

# DHCP: Dynamic Host Configuration Protocol

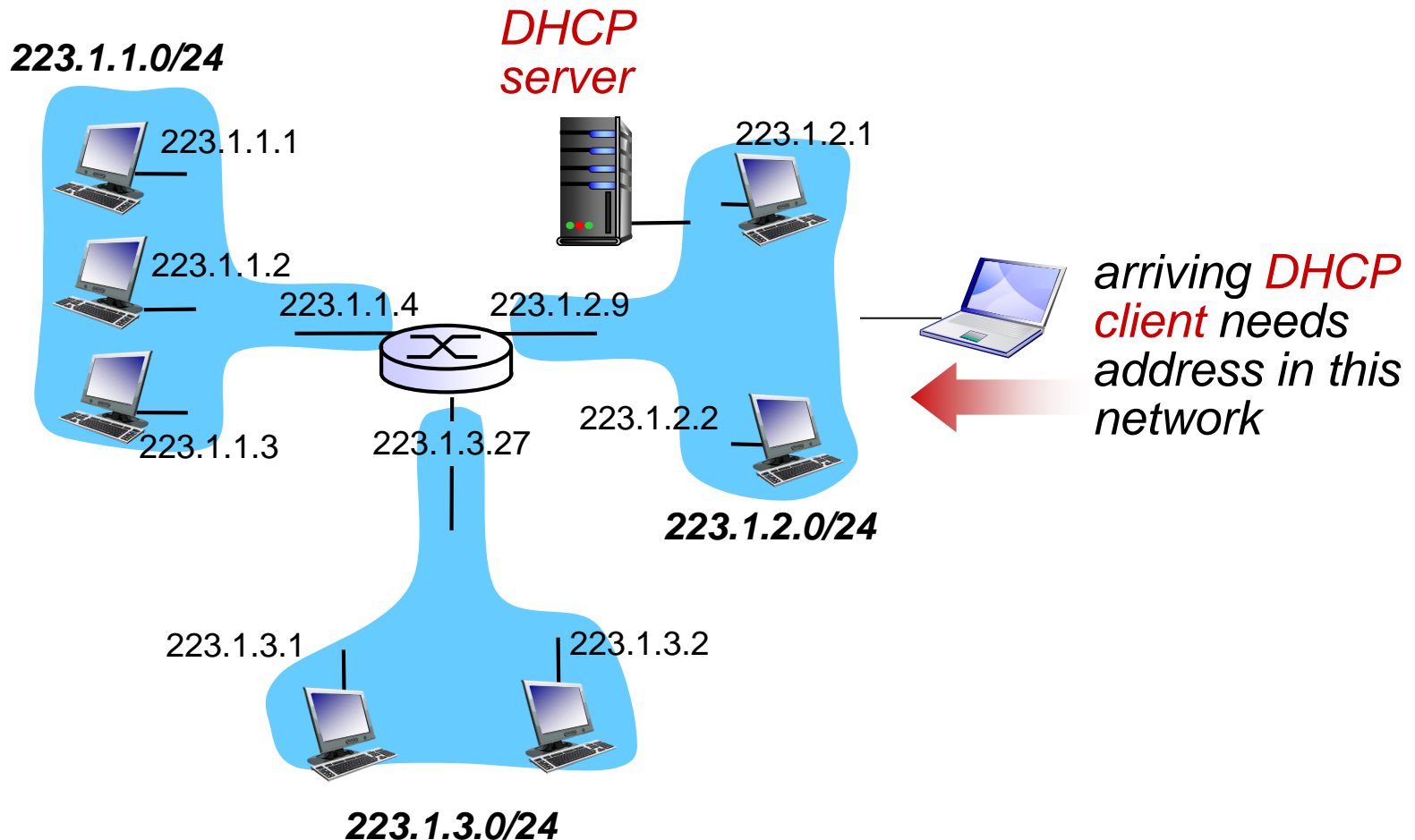
*goal:* allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/“on”)
- support for mobile users who want to join network (more shortly)

## *DHCP overview:*

- host broadcasts “**DHCP discover**” msg [optional]
- DHCP server responds with “**DHCP offer**” msg [optional]
- host requests IP address: “**DHCP request**” msg
- DHCP server sends address: “**DHCP ack**” msg

# DHCP client-server scenario



# DHCP client-server scenario

DHCP server: 223.1.2.5

DHCP discover

arriving  
client



Broadcast: is there a  
DHCP server out there?

DHCP offer

Broadcast: I'm a DHCP  
server! Here's an IP  
address you can use

DHCP request

Broadcast: OK. I'll take  
that IP address!

DHCP ACK

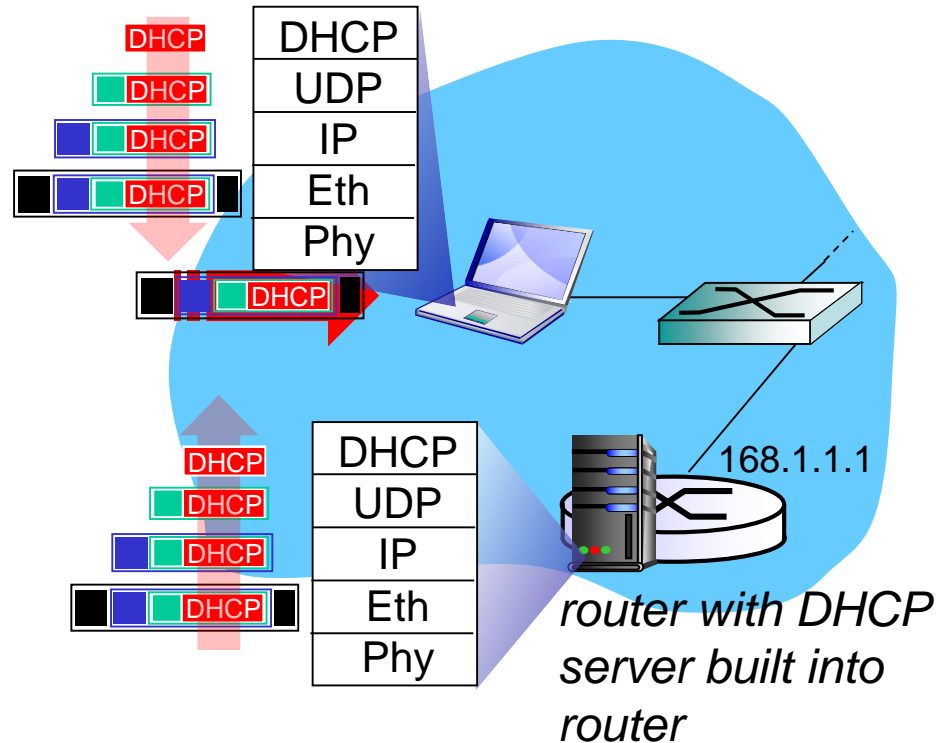
Broadcast: OK. You've  
got that IP address!

# DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

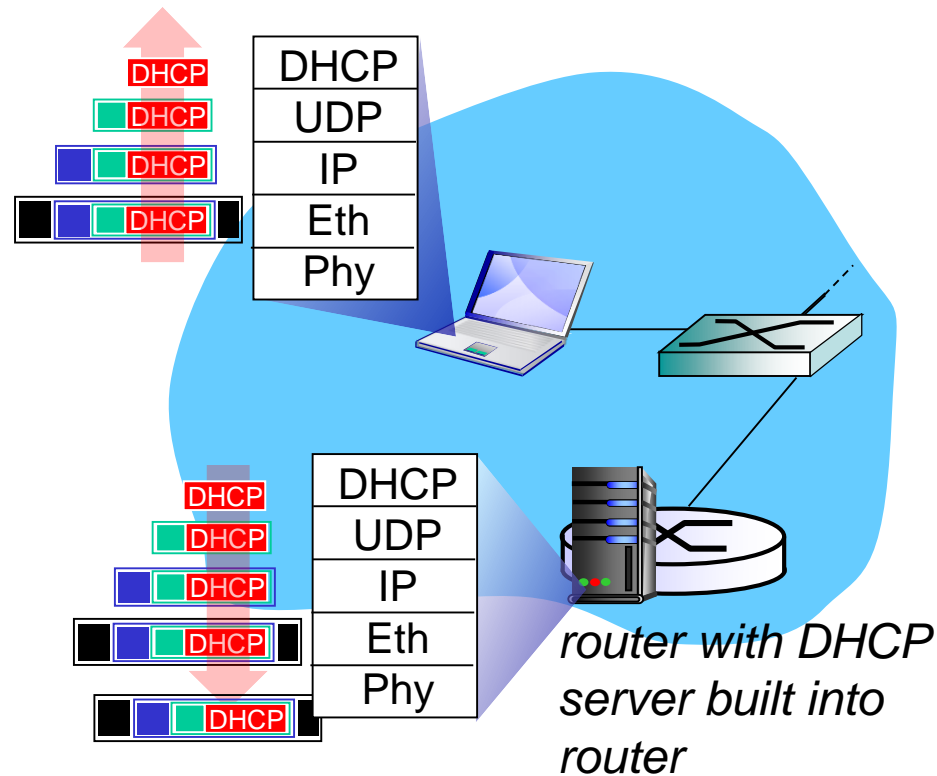
- address of first-hop router for client
- name and IP address of DNS server
- network mask (indicating network versus host portion of address)

# DHCP: example



- connecting laptop needs its IP address, addr of first-hop router, addr of DNS server: use DHCP
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.1 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demuxed to IP demuxed, UDP demuxed to DHCP

# DHCP: example



- DHCP server formulates DHCP ACK containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client
- client now knows its IP address, name and IP address of DNS server, IP address of its first-hop router

# IP addressing: the last word...

**Q:** how does an ISP get block of addresses?

**A: ICANN:** Internet Corporation for Assigned

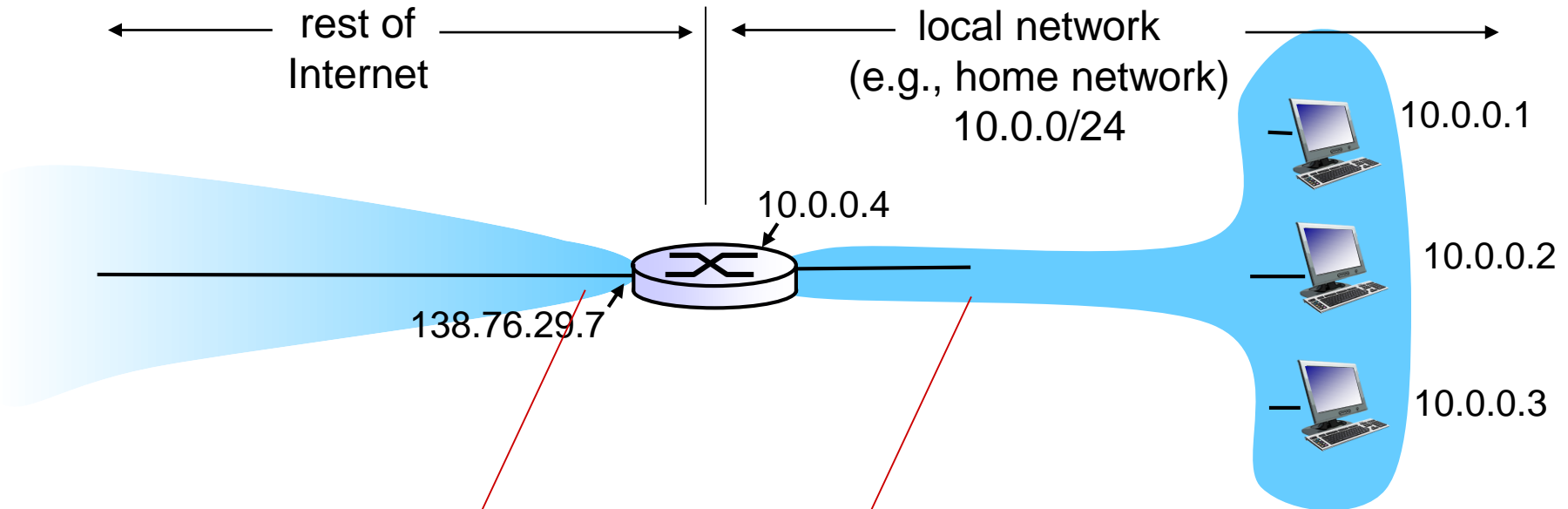
Names and Numbers

<http://www.icann.org/>

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes



# NAT: network address translation



*all* datagrams *leaving* local network have *same* single source NAT IP address: 138.76.29.7, different source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

# NAT: network address translation

*motivation:* local network uses just one IP address as far as outside world is concerned:

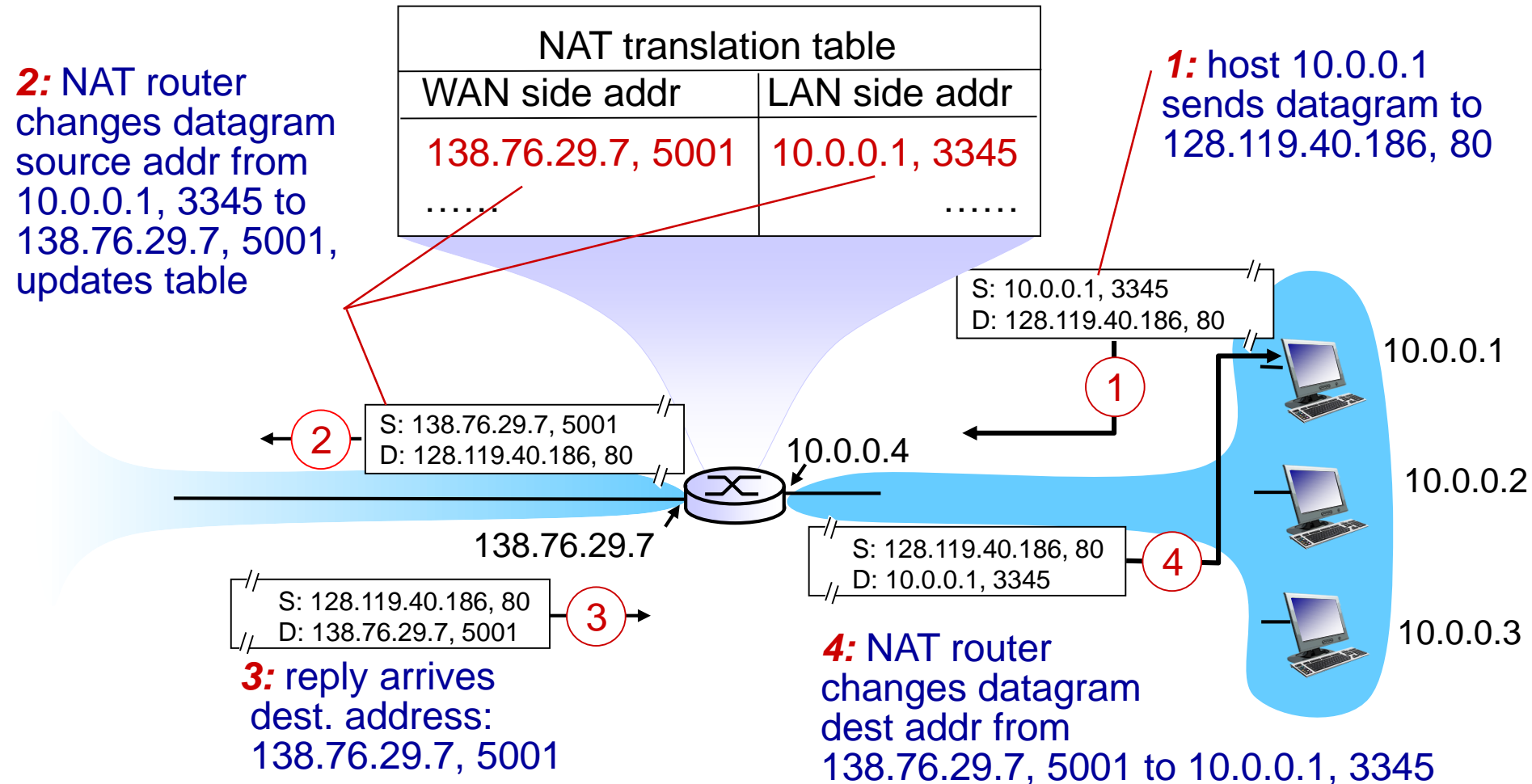
- range of addresses not needed from ISP: just one IP address for all devices
- can change addresses of devices in local network without notifying outside world
- can change ISP without changing addresses of devices in local network
- devices inside local net not explicitly addressable, visible by outside world (a security plus)

# NAT: network address translation

*implementation:* NAT router must:

- *outgoing datagrams: replace* (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - ... remote clients/servers will respond using (NAT IP address, new port #) as destination addr
- *remember (in NAT translation table)* every (source IP address, port #) to (NAT IP address, new port #) translation pair
- *incoming datagrams: replace* (NAT IP address, new port #) in dest fields of every incoming datagram with corresponding (source IP address, port #)

# NAT: network address translation



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## 4.4 Generalized Forward and SDN

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- OpenFlow examples of match-plus-action in action

# IPv6: motivation

- *initial motivation*: 32-bit address space soon to be completely allocated.
- additional motivation:
  - header format helps speed processing/forwarding
  - header changes to facilitate QoS

## *IPv6 datagram format:*

- fixed-length 40 byte header
- no fragmentation allowed

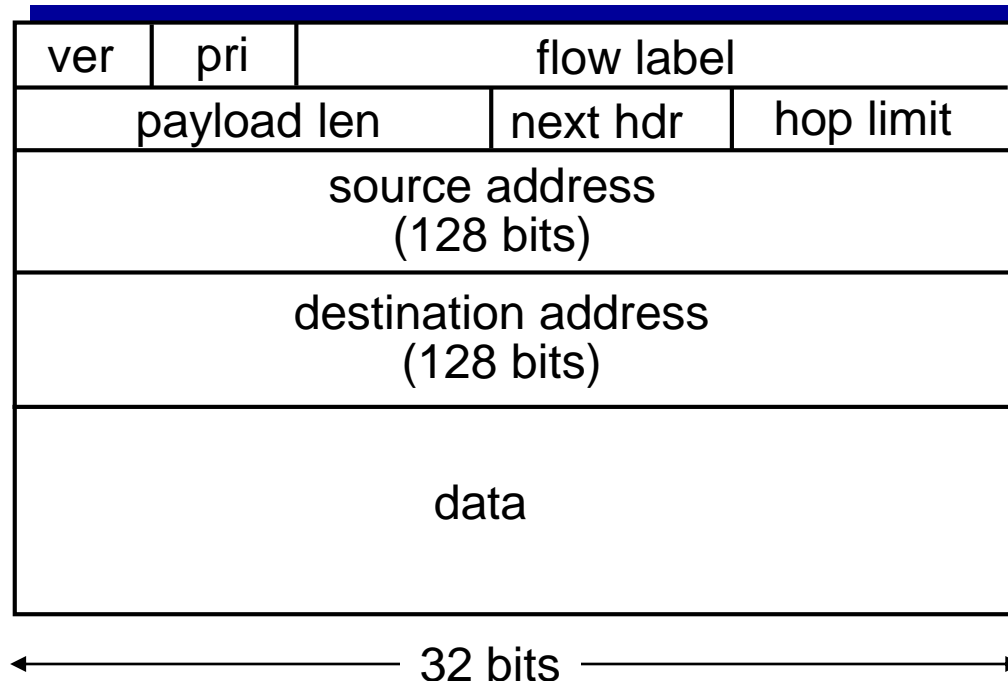
# IPv6 datagram format

*priority:* identify priority among datagrams in flow

*flow Label:* identify datagrams in same “flow.”

(concept of “flow” not well defined).

*next header:* identify upper layer protocol for data



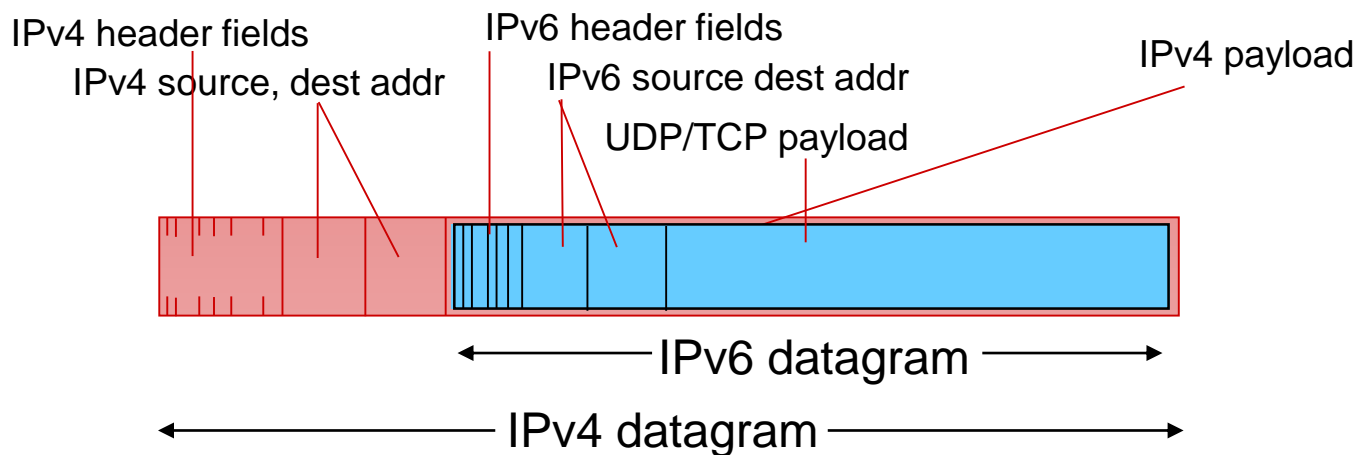
# Other changes from IPv4

- *checksum*: removed entirely to reduce processing time at each hop
- *options*: allowed, but outside of header, indicated by “Next Header” field
- *ICMPv6*: new version of ICMP
  - additional message types, e.g. “Packet Too Big”
  - multicast group management functions



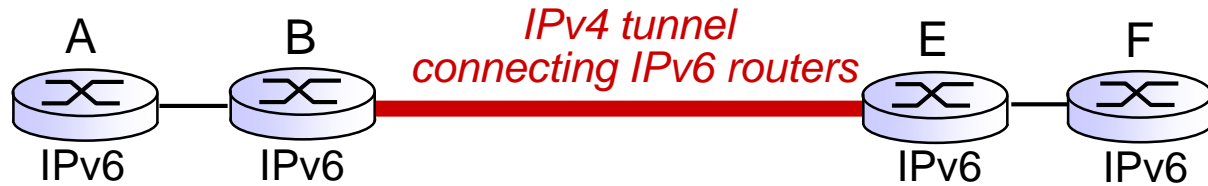
# Transition from IPv4 to IPv6

- not all routers can be upgraded simultaneously
  - no “flag days”
  - how will network operate with mixed IPv4 and IPv6 routers?
- **tunneling**: IPv6 datagram carried as *payload* in IPv4 datagram among IPv4 routers

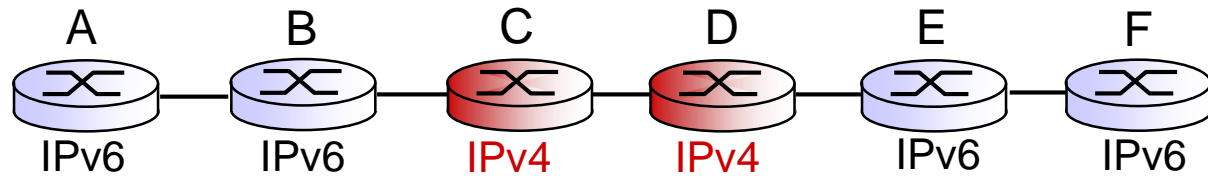


# Tunneling

logical view:

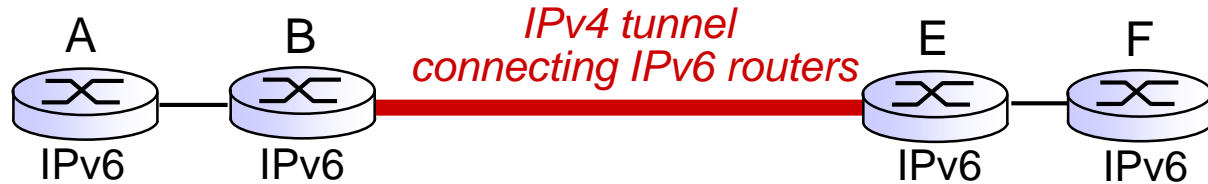


physical view:

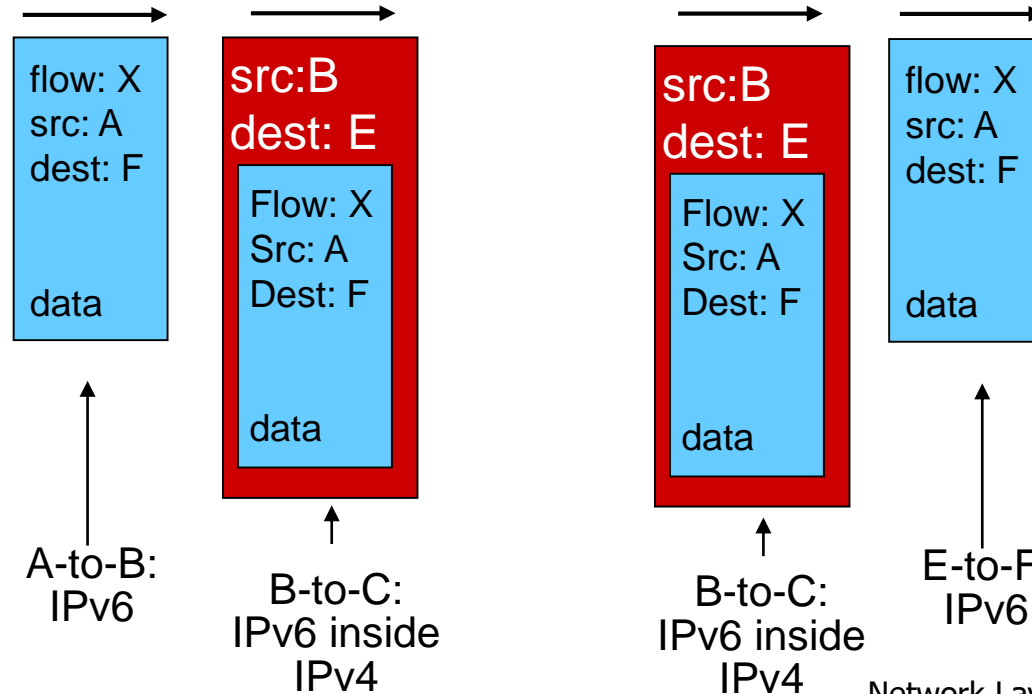
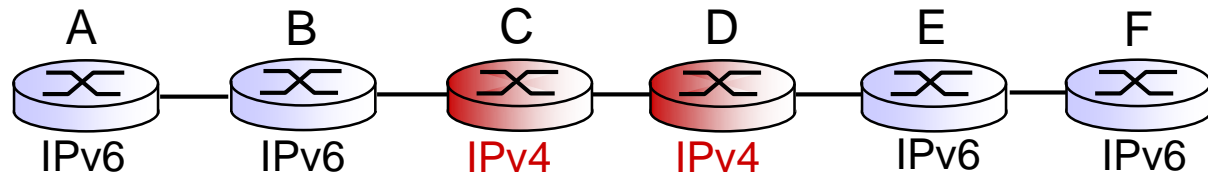


# Tunneling

logical view:



physical view:



# IPv6: adoption

- Google: 8% of clients access services via IPv6
- NIST: 1/3 of all US government domains are IPv6 capable
- *Long (long!) time for deployment, use*
  - 20 years and counting!
  - think of application-level changes in last 20 years: WWW, Facebook, streaming media, Skype, ...
  - *Why?*

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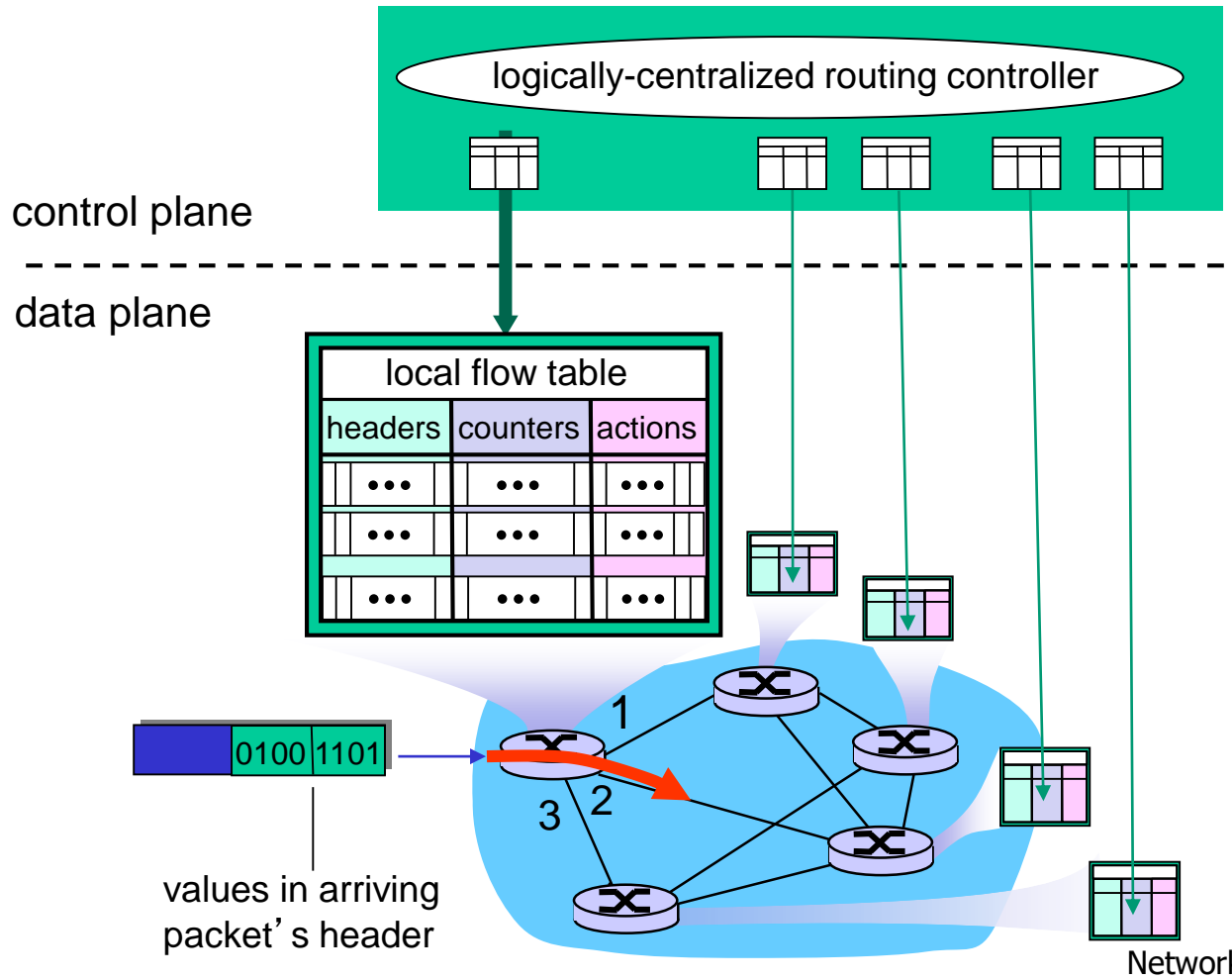
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## 4.4 Generalized Forward and SDN

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# Generalized Forwarding and SDN

Each router contains a *flow table* that is computed and distributed by a *logically centralized routing controller*



# OpenFlow data plane abstraction

- *flow*: defined by header fields
- generalized forwarding: simple packet-handling rules
  - *Pattern*: match values in packet header fields
  - *Actions: for matched packet*: drop, forward, modify, matched packet or send matched packet to controller
  - *Priority*: disambiguate overlapping patterns
  - *Counters*: #bytes and #packets

*Flow table in a router (computed and distributed by controller) define router's match+action rules*

# OpenFlow data plane abstraction

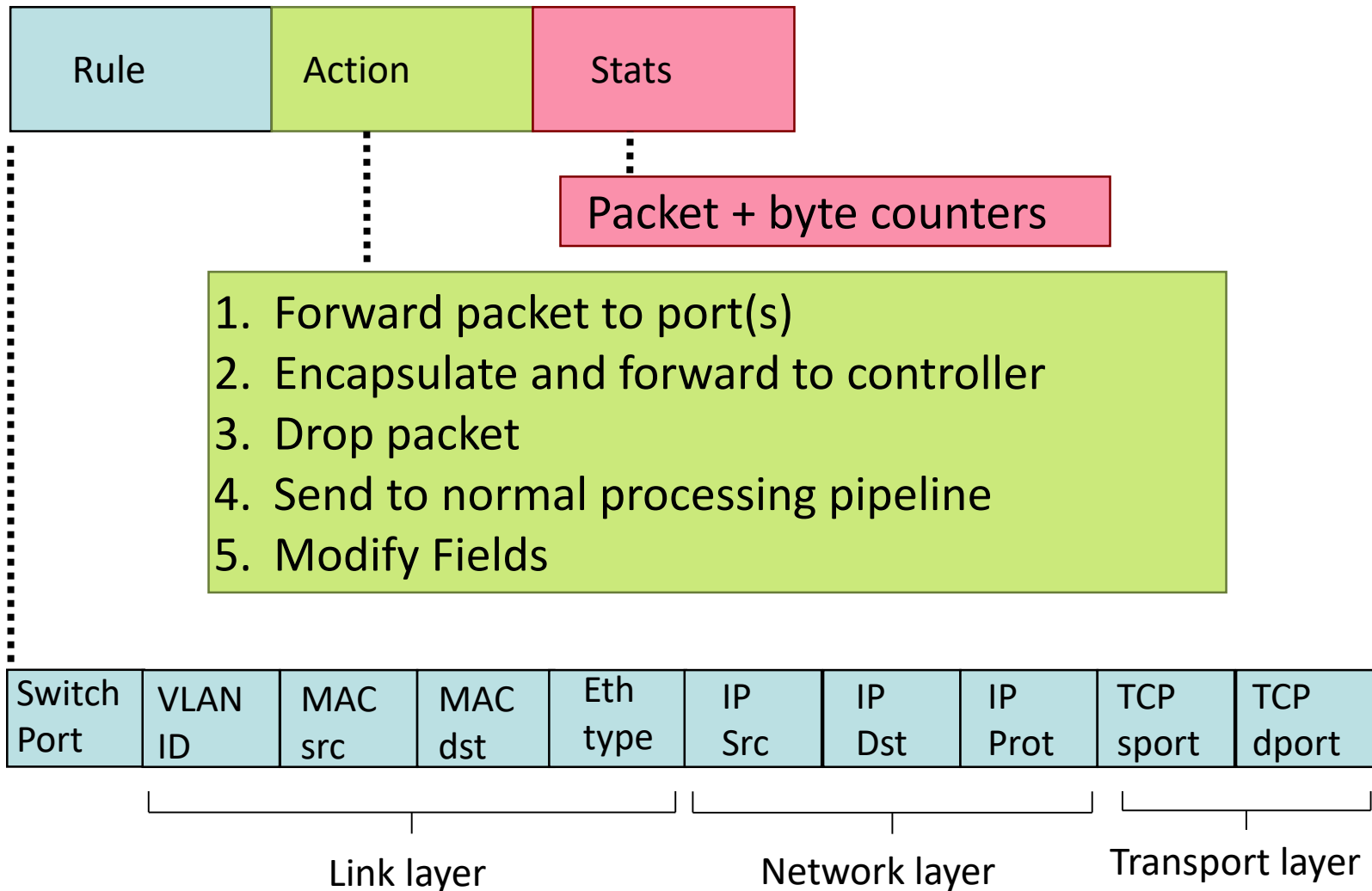
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\* : wildcard

1. src=1.2.\*.\*, dest=3.4.5.\* → drop
2. src = \*.\*.\*.\*, dest=3.4.\*.\* → forward(2)
3. src=10.1.2.3, dest=\*.\*.\*.\* → send to controller



# OpenFlow: Flow Table Entries



# Examples

## Destination-based forwarding:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	*	51.6.0.8	*	*	*	port6

*IP datagrams destined to IP address 51.6.0.8 should be forwarded to router output port 6*

## Firewall:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	*	*	*	*	22	drop

*do not forward (block) all datagrams destined to TCP port 22*

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	128.119.1.1	*	*	*	*	drop

*do not forward (block) all datagrams sent by host 128.119.1.1*

# Examples

## Destination-based layer 2 (switch) forwarding:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	22:A7:23: 11:E1:02	*	*	*	*	*	*	*	*	port3

*layer 2 frames from MAC address 22:A7:23:11:E1:02  
should be forwarded to output port 6*

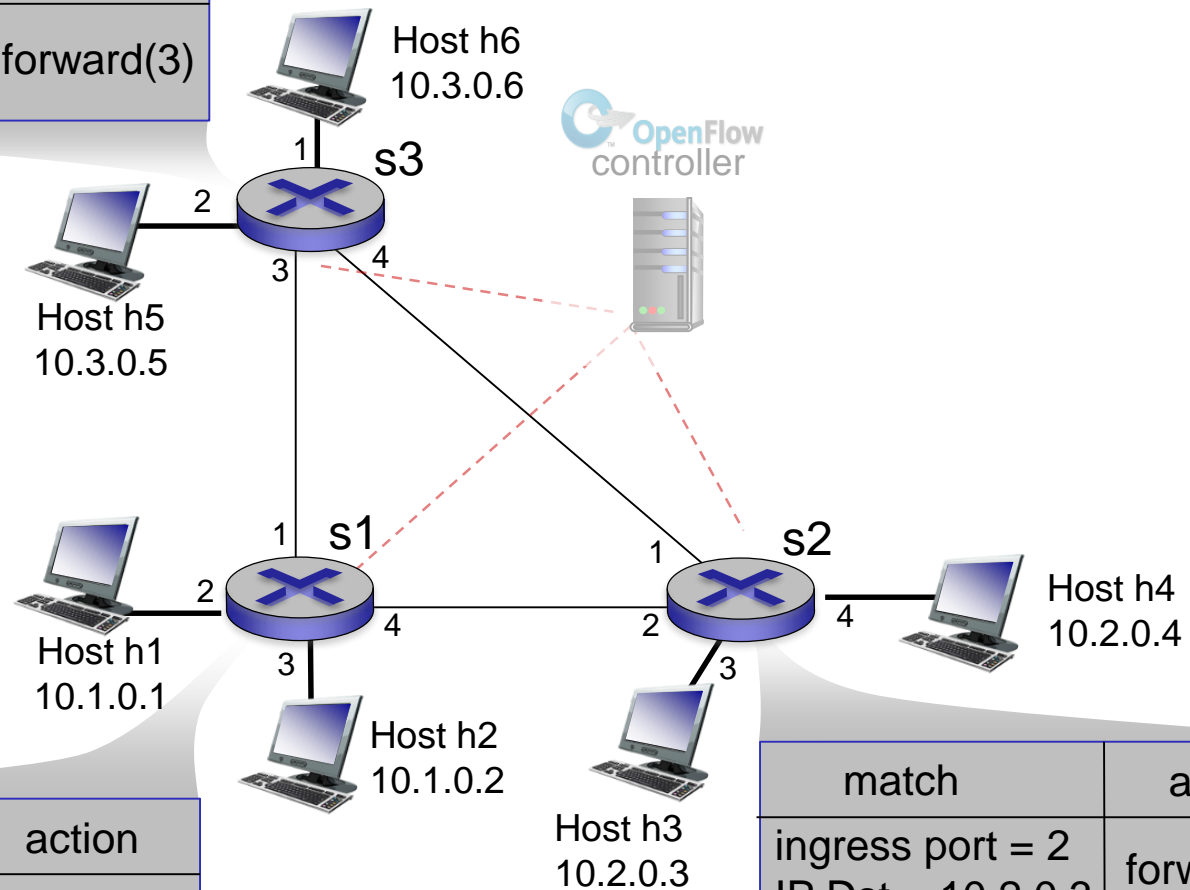
# OpenFlow abstraction

- *match+action*: unifies different kinds of devices
- Router
  - *match*: longest destination IP prefix
  - *action*: forward out a link
- Switch
  - *match*: destination MAC address
  - *action*: forward or flood
- Firewall
  - *match*: IP addresses and TCP/UDP port numbers
  - *action*: permit or deny
- NAT
  - *match*: IP address and port
  - *action*: rewrite address and port

# OpenFlow example

*Example:* datagrams from hosts h5 and h6 should be sent to h3 or h4, via s1 and from there to s2

match	action
IP Src = 10.3.*.* IP Dst = 10.2.*.*	forward(3)



match	action
ingress port = 1 IP Src = 10.3.*.* IP Dst = 10.2.*.*	forward(4)

match	action
ingress port = 2 IP Dst = 10.2.0.3	forward(3)
ingress port = 2 IP Dst = 10.2.0.4	forward(4)